National Research Council of Canada

Division of Physics

APS - 477

SNOWMOBILE NOISE
ITS SOURCES, HAZARDS AND CONTROL

ACOUSTICS SECTION
DIVISION OF PHYSICS
NATIONAL RESEARCH COUNCIL OF CANADA
OTTAWA, 1970

Ottawa

N. R. C. 11272

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NOTE This report is divided into three sections which are arranged in order of increasing technical complexity.

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1 A BRIEF DISCUSSION OF THE SUBJECT

1.1 Introduction

The popularity and number of snowmobiles has grown considerably in the last few years. As is the case with many new devices, their introduction to the existing environment creates several problems. For snowmobiles these are generally recognized to be in the areas of noise, health and safety.

We have already published a guide to the general control of noise in urban areas[1]. This report considered a variety of sources of noise, including snowmobiles, and suggested limits that could justifiably be enforced by law. The present work is the result of a short investigation into the noise produced by snowmobiles, and describes the levels they produce, the methods for quieting the machines, and also the effect of existing levels on the health and safety of the operator. Our aim in this work was not to limit the pleasure or utility of these machines but rather to make them more acceptable to both participants and non-participants.

1.2 A Measure of the Problem

In order to form an overall impression of the problem of snowmobile noise it is instructive to examine first some statistical evidence. Figure 1 shows a histogram of noise made by a random selection of 50 snowmobiles (including about 15 brands) measured in the field under a variety of typical operating conditions. The range of sound levels is quite large, namely from 79 to 102 dBA (the measurement of sound level in dBA has been found to correlate well with loudness and is related to annoyance). An 'average' snowmobile

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[1] "A Brief Study of A Rational Approach to Legislative Control of Noise"
Report APS-467. Applied Physics Division, National Research Council of Canada (1968)

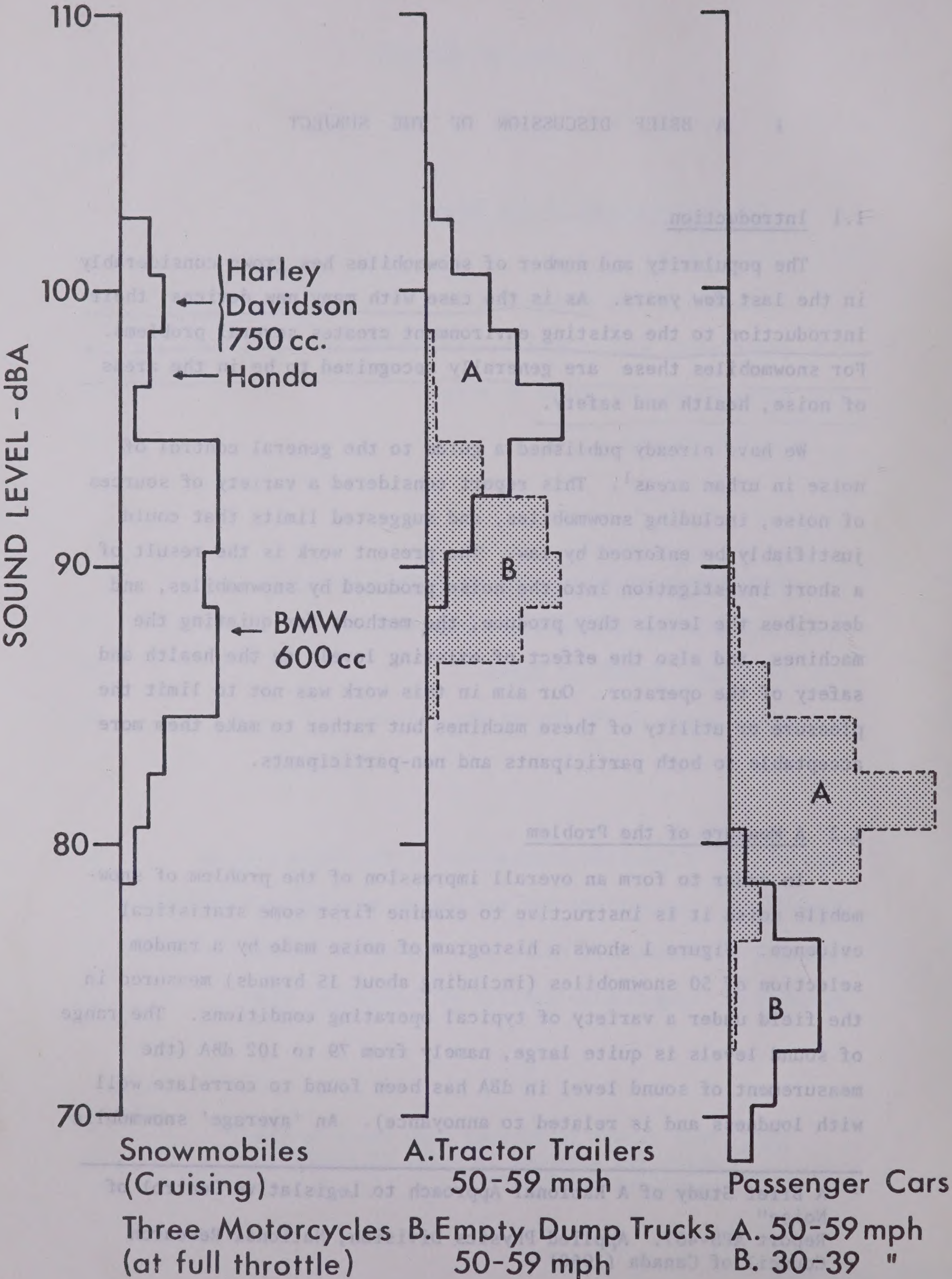


Fig. 1 - Distribution of Noise Levels produced by snowmobiles and other vehicles. All measurements at 15 feet.

when cruising may be expected to produce a level of approximately 90 dBA at the standard distance of 15 feet. This distance will be implied in all subsequent measurements unless otherwise specified.

To put this information in perspective it may be useful to compare it, in Figure 1, with similar statistical distributions for some familiar vehicles at specified speeds. It is evident that the average and noisier than average snowmobiles, when cruising, produce sound levels which are comparable with those of tractor-trailers and empty dump trucks at speeds in the range 50 - 59 mph. The quietest snowmobiles are comparable in noise output with passenger cars travelling at 50 - 59 mph but few are as quiet as passenger cars at 30 - 39 mph. Unfortunately such detailed statistics are not yet available for motorcycles; instead sound levels are given for three motorcycles, at full throttle, which were previously chosen as representative[1]. Clearly snowmobiles are among the noisiest of motor vehicles.

1.3 Experiments with a Typical Snowmobile

A number of tests were performed on a machine (Ski-Doo "Olympique 335" manufactured by Bombardier) which the field measurements indicated to be representative of a large proportion of those in use. It was found that the muffler and cowl put on by the manufacturer already provided 20dBA of quieting. For further silencing one must reduce the noise generated by (1) the exhaust from the engine, (2) the intake of air to the carburetor and (3) the radiation from the outside surface of the engine and muffler. With materials that came readily to hand, 9 dBA of quieting was achieved without significantly affecting the mechanical performance of the machine. The maximum noise output of the modified machine was 85 dBA. This is the level previously recommended for legislation controlling snowmobile noise in urban areas. It is our opinion that this noise reduction could be achieved in a production model, following the above principles, without excessive penalty to mechanical performance or cost. This conclusion should apply to most popular machines.

1.4 The Exposure of the Driver to Noise

The sound level measured at the driver's ear is 113 dBA for the snowmobile described above, when operated at full power, and~110 dBA when cruising. These levels and those for other existing machines present a definite hazard to hearing. Accordingly, operators of snowmobiles are advised to wear some form of ear protection or to restrict the use of their machines to safe exposure times based on accepted criteria for hearing conservation. The modifications made to the test snowmobile reduced the level at the ear of the driver by 10 dBA, an amount which would allow a four-fold increase in exposure time for the same risk of hearing loss.

1.5 Recommendations

These recommendations follow from the work described briefly above and in detail in later sections (see Table of Contents).

1. Manufacturers should provide quieter snowmobiles in order to

   (a) eliminate the risk of permanent damage to the hearing of the driver (this would require that the noise level at the driver's ear be no greater than 90 dBA).

   (b) allow the driver to hear warning signals (e.g. car horn) at greater distances.

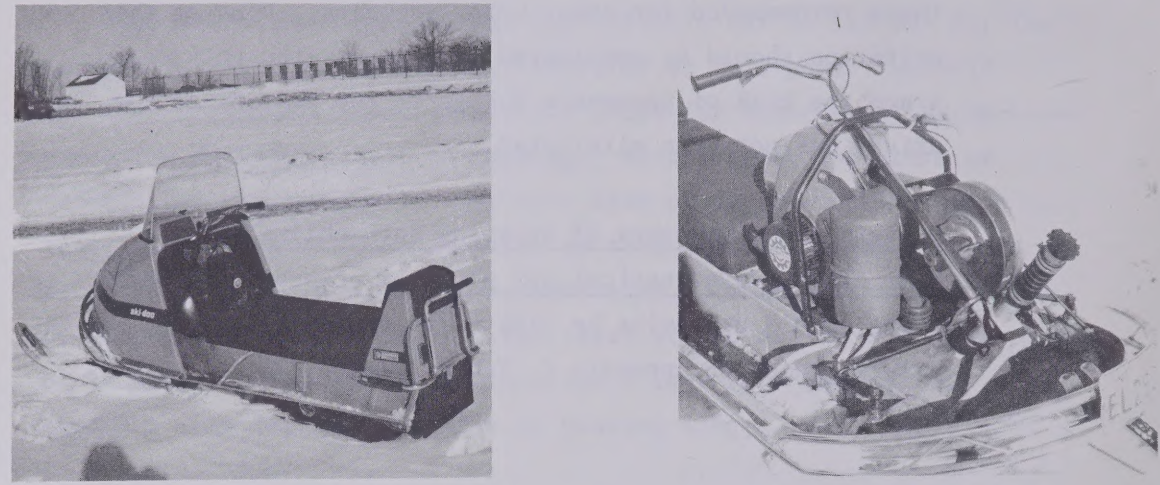
   (c) minimize annoyance to non-participants.

   (d) meet the recommended legal noise levels under any operating condition.

2. Legislation should be adopted to limit the noise from snowmobiles to 85 dBA measured at a distance of 15 feet.

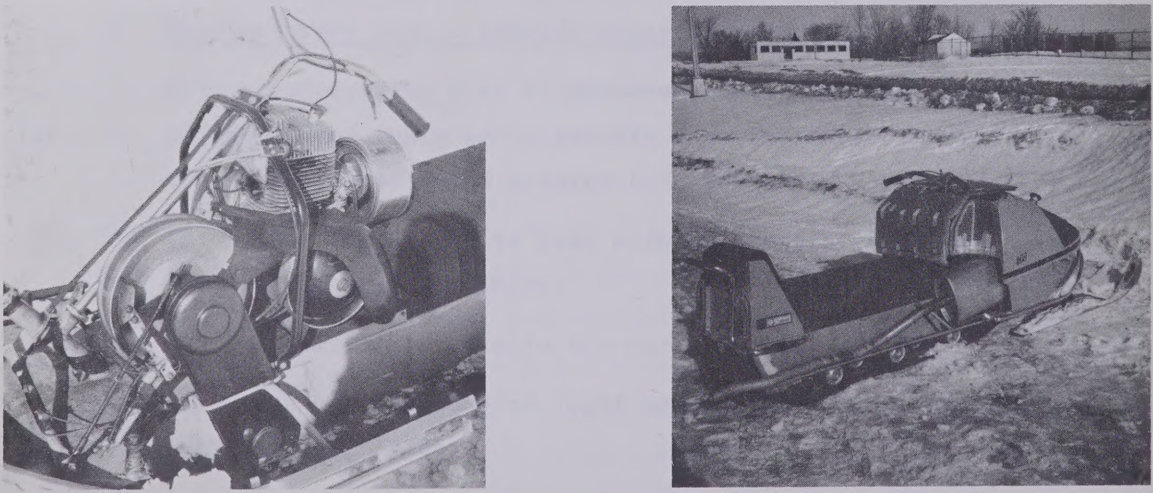
   This level would allow many existing machines to move at low throttle settings but few at higher throttle settings. Our experiments show that it is feasible to produce a machine that can be operated at full throttle within this noise limit. From the point of view of noise pollution and annoyance this level is compatible with those recommended for other motor vehicles. Meeting this criterion should be considered as a first step only, since the risk of permanent damage to the hearing of the driver has not been eliminated.

3. Drivers and passengers of existing snowmobiles should wear effective acoustical ear plugs or covers. Operating times should otherwise be limited to the restrictive values stated in Appendix C, Table 2 (page 31).



A. Stock Machine

B. Machine with Cowl
Removed.



C. Engine detail showing
air-intake muffler

D. Fully modified machine

Figure 2 Photographs showing the test snowmobile in various stages of modification.

2 MEASUREMENT OF NOISE FROM INDIVIDUAL MACHINES

2.1 Full Throttle Acceleration Experiments

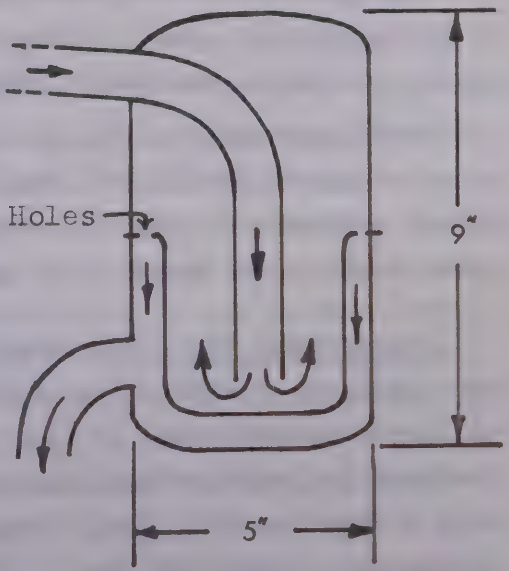
(a) The Machine

The snowmobile used in these experiments was a Bombardier Ski-Doo "Olympique 335".[2] It is conventional in its design and consists basically of a chassis, an engine, a power train and a track drive.

The engine is a lightweight, air-cooled, one cylinder two cycle unit (capacity 335 cc, 18 H.P.) which is located in front of the driver as shown in Figure 2A. The carburetor faces the rear of the machine and is attached to the engine under the small cover visible in the photograph. The air intake to the engine is thus situated directly in front of the driver and is not significantly muffled or filtered. The active engine unit is rubber mounted to the chassis.

The exhaust system is assembled in the factory to form a single component and is rigidly bolted to the engine (see Figure 2B). The engine exhaust gases flow down a single-walled metal pipe which penetrates the main cavity of the muffler, as shown in the diagram. The volume of this muffler is 175 cu. in. The tailpipe is attached to the small cavity between the two cylinders and, passing through the chassis in a rubber bushing, discharges the exhaust into the track compartment.

Muffler Section



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[2] We wish to acknowledge the friendly cooperation of Mr. M. Armstrong, manager, Capital Coach Trailer Sales Ltd., Ottawa, who supplied the machines and additional parts used in this study.

It can be seen, from Figure 2A, that the engine and carburetor are not completely enclosed by the plastic (polycarbonate) cowl, which is attached to the chassis by four clips.

The power train includes a form of automatic transmission consisting of two centrifugally activated variable-diameter pulleys connected by a rubber 'V' belt. The clutch consists of a drive pulley whose flanges are separated when the engine is idling. The effective diameter of the driven pulley is reduced as its speed increases and power is transmitted to the track by means of an enclosed chain drive. The track suspension uses independently sprung rubber-tired bogie wheels.

(b) Experimental Procedure

Measurement of Sound Level. The output of a precision sound level meter (Bruel and Kjaer, type 2203) was recorded using a Tandberg Model 11 portable magnetic tape recorder. The recording was later analysed using a Bruel and Kjaer type 1612 Bandpass Filter Set to yield octave-band spectra and dBA levels.

The apparatus was calibrated using the internal reference signal of the sound level meter. Estimated accuracy of the octave-band results, including temperature effects, is ± 1 dB.

A-weighted sound levels were also measured directly using small portable sound level meters, either a Bruel and Kjaer, type 2205 or a Rhode and Schwartz, type ELT. These were also used to obtain the noise levels at the driver's ear and the data shown in Figure 1.

Acceleration Test. The snowmobile was run on a prepared track that consisted of about 6 inches depth of packed snow. The machine was accelerated from rest at full throttle and driven in a straight line past the noise measuring equipment. The sound level meters were held 15 feet from this line, 4 feet from the ground, and pointed horizontally towards the track. The distance from the start of each run to the recording instruments was 60 feet. The machine was travelling at approximately 20 mph when passing the test location.

The snow surrounding the prepared track had recently fallen and was not packed down. Other full throttle acceleration tests were conducted at temperatures as low as -5°F and under a variety of snow conditions. The noise levels at 15 feet did not vary significantly, although the traction of the machine changed somewhat.

The time taken for the snowmobile to accelerate from rest to the end of the 60 foot run was measured using a stopwatch. This information effectively provided a dynamometer test and was used to check that any modifications made to the machine did not significantly alter its performance. Our confidence in these measurements was limited to ± 10%. Modifications which resulted in acceleration times outside these limits were rejected.

(c) Results and Discussion

The levels of noise in the octave bands shown graphically in Figure 3 and the noise levels listed there in dBA were all obtained by the procedure described in the previous section. Each level is the average of two measurements taken on different runs of the snowmobile, which usually differed by less than 1 dB.

Curve A for no muffler or cowl on the machine is a measure of the capacity of the engine for producing noise. The level of 114 dBA is high, and the spectrum is rich in mid and high frequency components; these qualities together define the very loud 'blatt' which is characteristic of any unmuffled engine. The effect of putting on the muffler supplied by the manufacturer was to change the spectrum from Curve A to Curve B. The main reduction of noise was in the middle and high frequency bands, which changed its quality to the familiar whine of the snowmobile. The muffling achieved was considerable, being 18 dBA, but the overall noise level was still high. It is seen from Curve C that putting on the standard cowl further reduced the high frequency components of the sound. However, the overall level was reduced only slightly (2 dBA) because the noise in the important mid-frequency bands in Curve B remained almost unchanged.

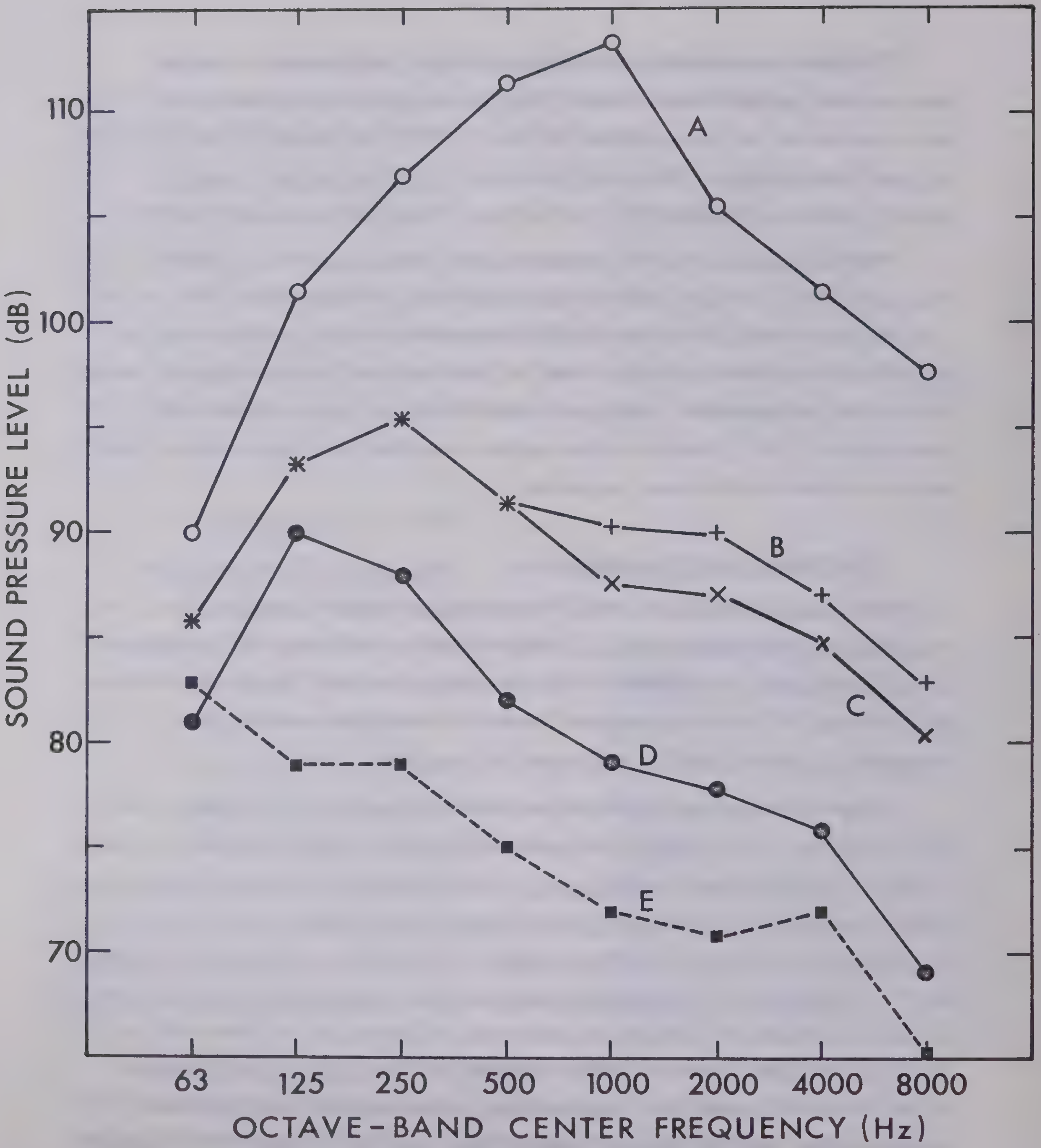


Figure 3 - Octave-band analysis of the noise generated by a representative snowmobile (one-cylinder, 335 c.c. displacement, 18 H.P.) modified in various ways.

A.	Cowl and muffler removed (see Fig 2C)	114 dBA
B.	Only cowl removed (Fig 2B)	96 dBA
C.	Stock machine (Fig 2A)	94 dBA
D.	Improved muffler, cowl, and air intake silencer	85 dBA
E.	Same improvements as D, but at constant ~10 mph	78 dBA

All measurements taken 15 feet to the right of the snowmobile accelerating under full throttle at ~ 20 mph except as noted.

It was possible to isolate the main sources of sound in the snowmobile by a series of experiments described in Appendix A. Impromptu modifications to the machine in the light of this knowledge, with materials which came easily to hand, produced a considerable reduction of the noise in the important mid-frequency region, as shown by Curve D, and hence a further reduction in level by 9 dBA to 85 dBA overall. The machine now sounded much more innocuous. This is, in fact, the level proposed for legislation controlling the noise from snowmobiles (see Appendix D).

The modifications were (a) the replacement of the snowmobile muffler with a standard car muffler (see Figure 6A); (b) the extension of the cowl by means of heavy cardboard to provide a better enclosure for the motor (see Figure 2D), and the lining of this cowl with sound absorbent material (1" duct-liner); and (c) the provision of a rudimentary air intake silencer made from a can and duct-liner (see Figure 2C). All three modifications were needed to reduce the overall level substantially. The role of the individual modifications in controlling the sound level is discussed in Appendix A.

These modifications were intended only to demonstrate that a considerable reduction of the noise from snowmobiles was feasible with rather simple means. We believe, however, that similar or even larger reductions could be achieved in a production model by appropriate design, based on the same principles, without a significant change in the mechanical performance of the machine.

(d) Effect of Mechanical Condition

The snowmobile used in these experiments and in others to be described later was in very good mechanical condition. We also tested a machine with the same model number (and manufacturer) which had been used more extensively. Acceleration tests indicated considerably less power, due apparently to poor mechanical condition, and the overall noise level was 5 dBA lower, but the shape of the spectrum was similar to that of Curve C in Figure 3 for the machine in good condition. We cannot predict, therefore, the noise a given machine will produce from its design alone, as specified by its model number. The noise level may be raised or lowered by its mechanical condition.

(e) Two Cylinders versus One

The mechanical design of the machine will influence its noise output. A commonly held opinion is that two-cylinder snowmobiles are quieter than singles. For this reason we measured a Ski-Doo Nordic model 399E, 24 H.P. under similar conditions to those described previously (section 2.1(b)), obtaining an overall level of 90 dBA compared to 94 dBA for the stock single-cylinder machine in good condition (Figure 3). These results appear to support the above opinion, but we note the machines are not otherwise equivalent; in particular the two-cylinder motor was more completely enclosed.

2.2 Cruising - Effect of Speed

The tests at full throttle described in section 2.1, are essentially a measure of the maximum noise that the snowmobile is capable of producing. In practice, of course, the noise output will depend on how the machine is being operated, and most particularly on the throttle opening and/or speed of the machine. To test this effect we measured the noise from the two-cylinder machine described in the previous section using the procedure in section 2.1(b), except that the throttle was held at a position just sufficient to maintain a constant speed. This speed was measured using a radar speed meter.

The snowmobile was operated at constant speeds of 10 and 6 mph (Curves B and C in Figure 4), and also at full throttle (Curve A). Curve D was obtained from measurements with the snowmobile stationery and the motor idling.

Note that the overall level is related to speed. The tonal character of the noise also changes as indicated by the change in shape of the spectrum. The position of the peak at low frequencies appears to be determined by the firing rate of the engine. This firing rate determines the pitch of the characteristic snowmobile whine.

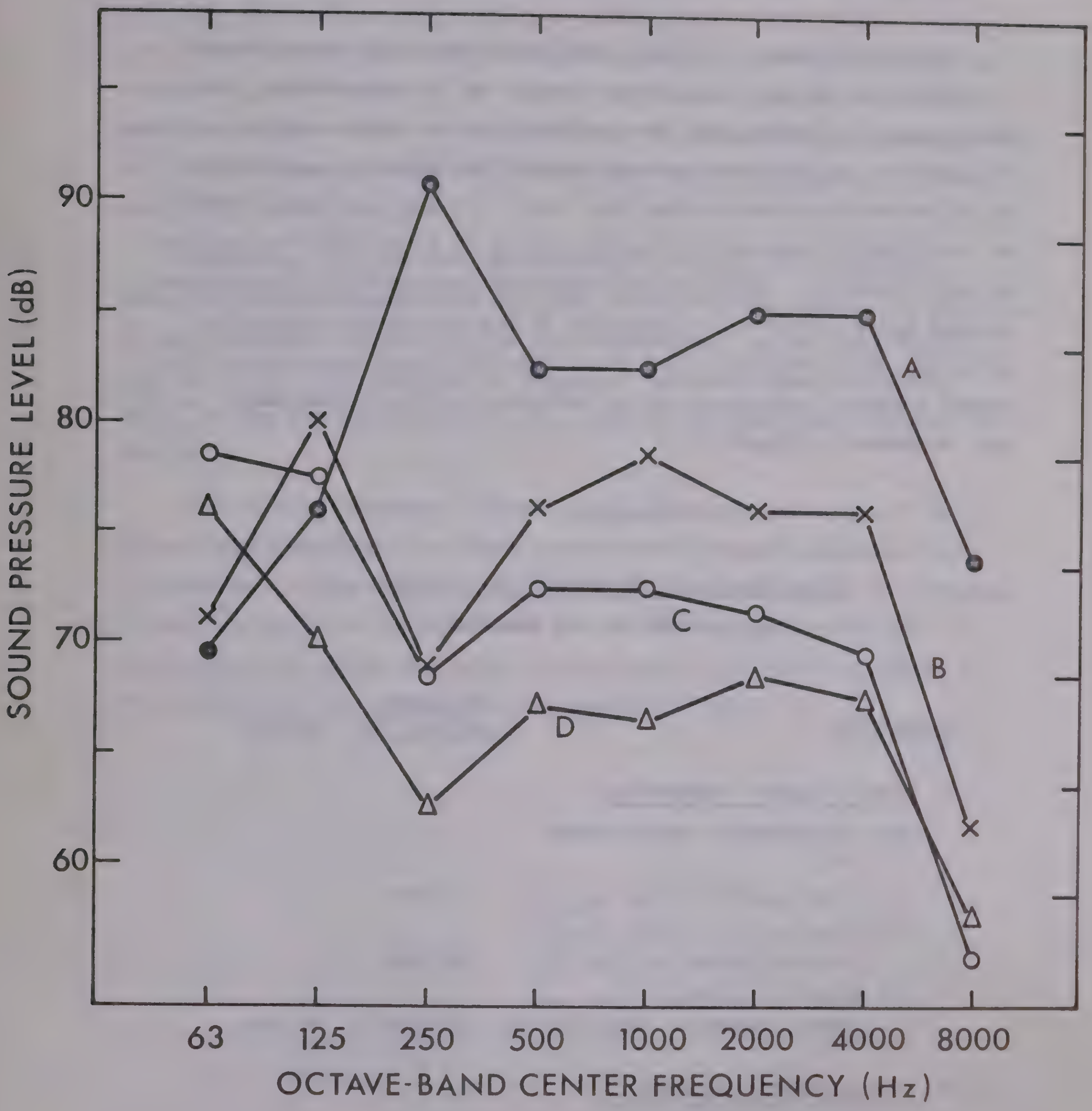


Figure 4 - Octave-band spectra for an unmodified two cylinder snowmobile under various operation conditions.

A.	Full throttle - 20 mph	90 dBA
B.	Cruising - 10 mph	82 dBA
C.	Slow cruising - 6 mph	75 dBA
D.	Snowmobile stationary, engine idling	66 dBA

2.3 Noise Level at the Ear of the Driver

The microphone in a sound level meter was held approximately 4 inches from the ear of a driver seated on the snowmobile. One measurement was taken with the machine at rest and the engine idling, the other by an observer running beside the snowmobile, which was in full-throttle acceleration from rest. It was possible in this way to obtain a reasonably stable reading (± 2 dBA) for the machine at full throttle. These two measurements represent the maximum and minimum noise levels to be expected at the ear of the driver or passenger when cruising. The levels for different speeds would be spaced between, approximately as indicated by the measurements at 15 feet recorded in Figure 4.

TABLE I

Noise Level at the Ear of the Driver
(when seated on the machine)

Snowmobile	Maximum Acceleration	Idling
A. One-cylinder snowmobile		
(for description see section 2.1(a))		
(1) Stock machine (see Fig 2A)	113 dBA	
(2) Stock machine with intake silencer shown in Fig 2C	108 dBA	
(3) Modified muffler, cowl and intake silencer (see Fig 2D)	103 dBA	80 dBA
B. Two-cylinder snowmobile		
(for description see section 2.1(e))		
Stock machine	106 dBA	86 dBA

The measurements in Table 1 are of the one-cylinder and two-cylinder snowmobiles described previously, and of the former machine with modifications described in section 2.1(c). Note that the noise reduction at the driver's ear due to the intake silencer alone is much larger than would be expected from the measurements at a distance of 15 feet shown in Figure 9, because the driver is closest to this source of noise.

Comparing the results in the Table with the full throttle acceleration measurements at 15 feet, we note there exists a difference of approximately 18 dBA for the stock machines. Using this figure, together with the histogram in Figure 1, we infer that the noise level at the ear of the driver of a typical machine when cruising is 108 dBA.

The risk of permanent damage to the hearing mechanism of the driver (and passenger) by these levels for different exposure times is discussed in Appendix C, together with their effect in the masking of other significant sounds, such as the horn of an automobile. A spectrum of the noise measured at the driver's ear when standing on the machine is also shown in this Appendix (Figure 10).

APPENDIX A

A DETAILED EXAMINATION OF THE NOISE SOURCES

(i) Exhaust Noise

It was evident from even casual listening that much of the machine noise was radiated from the exhaust. Accordingly measures were taken, first of all, to explore possibilities for quieting this source. The approach was simply to replace the stock muffler with other mufflers, all of which were readily available, and which, individually, had something distinctive to offer.

In the examination of a single noise source, such as the exhaust, it is desirable to have all other noises suppressed to the maximum possible extent. Ideally, the engine compartment would have been totally enclosed with an improved cowl. However, for practical reasons, it was not possible to conduct the muffler tests with the cowl in place.

For these experiments the machine was fitted with a simple air intake muffler consisting of a metal can lined with Fiberglas 1" duct liner. The can was installed in such a way that the inflowing air was forced to negotiate a 180° turn en route to the carburetor air intake (see the inset on Figure 9 and Figure 2C for details of construction). The acoustical performance of this muffler is discussed in part (iii) of this Appendix.

Any modifications which caused a significant loss of engine power, as indicated by acceleration times, were rejected. Such a loss of engine power may arise due to a restricted airflow into the engine or as a consequence of back pressure in the exhaust system.

Figure 5 displays octave-band spectra and overall sound levels in dBA for the machine with no muffler, and with the four mufflers used in these tests. Figure 6 shows photographs of these mufflers as installed at the end of the same 30" flexible exhaust pipe.

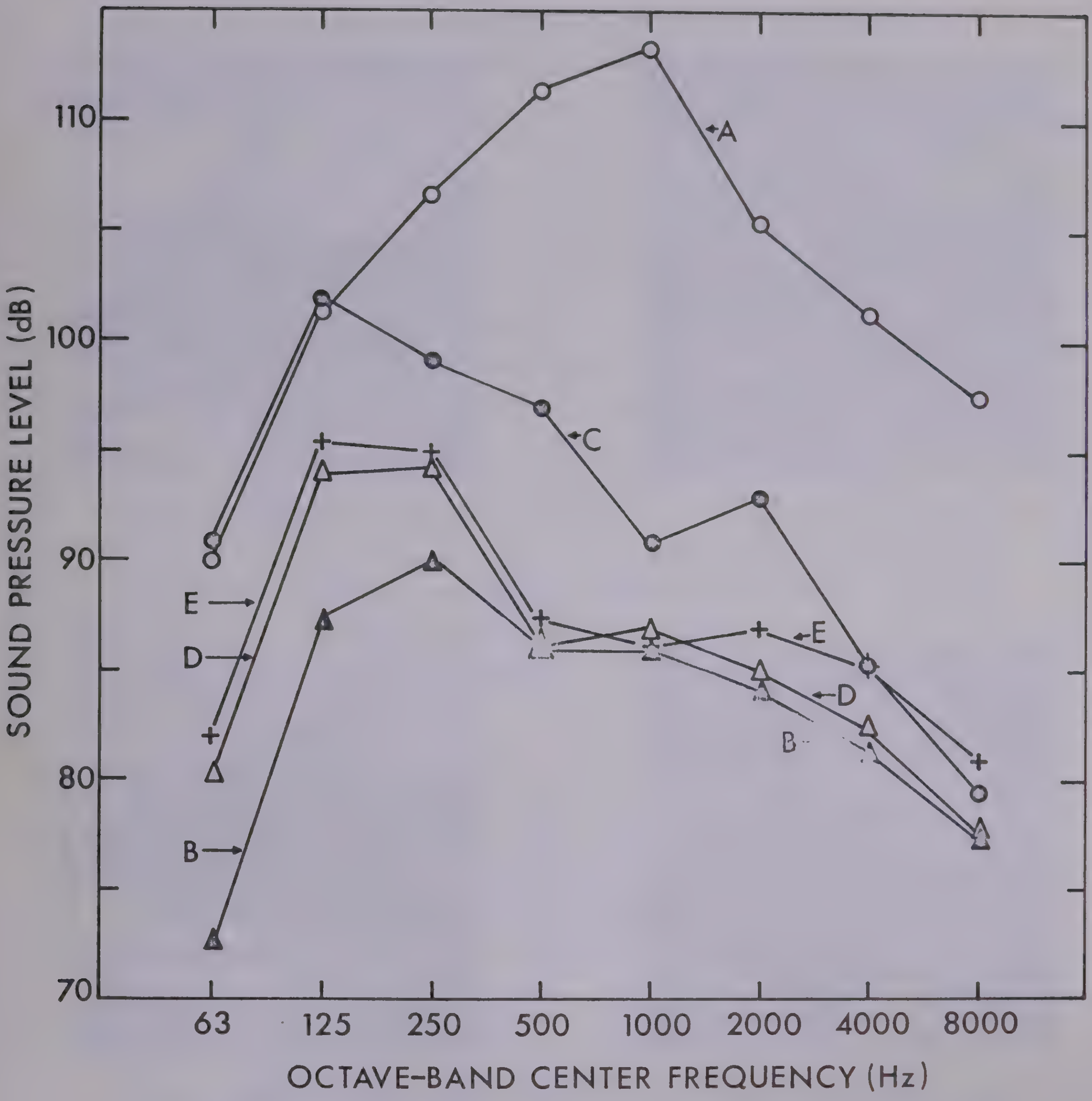
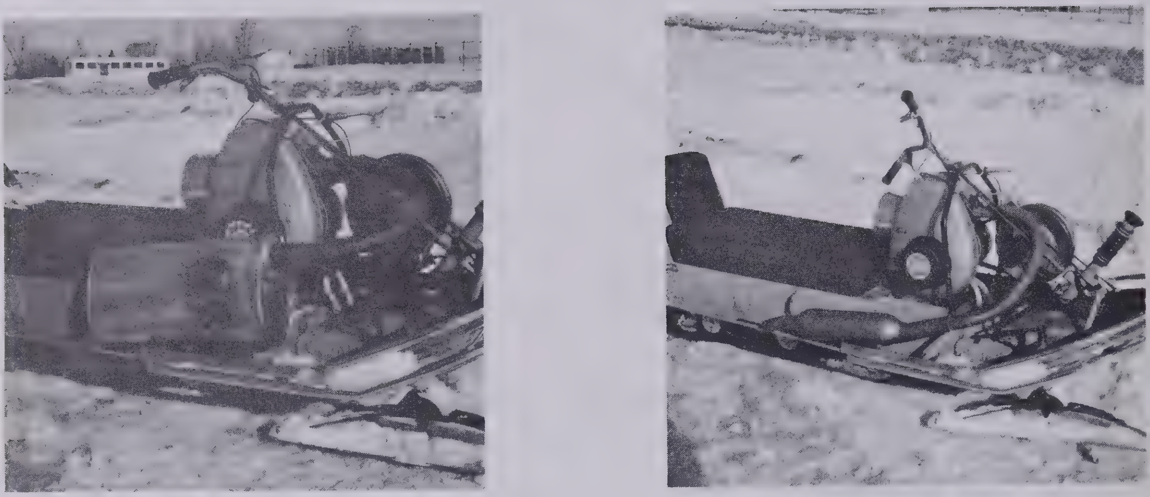


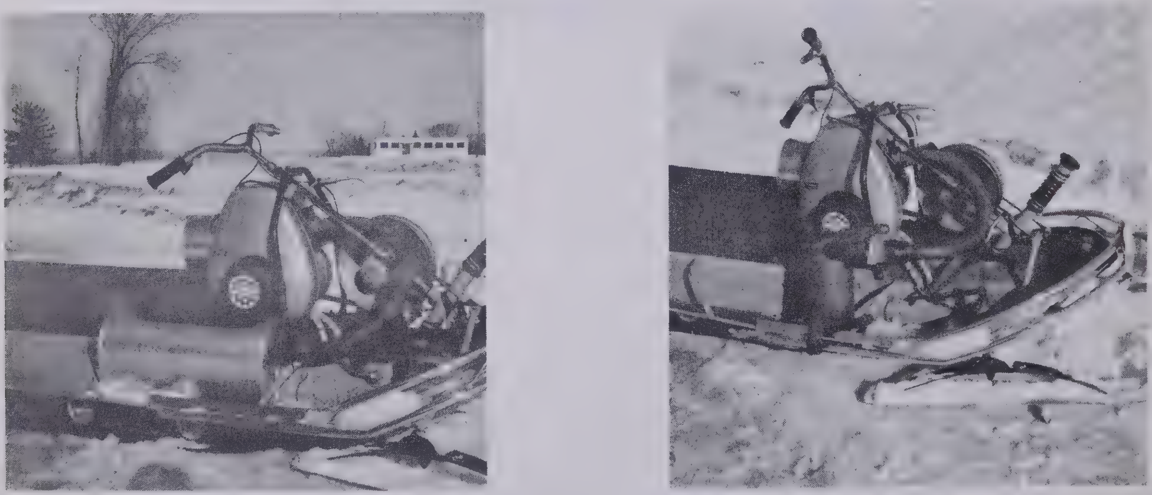
Figure 5 - A comparison of octave-band spectra for the test snowmobile with no muffler and when fitted with various different mufflers at the end of a 30" flexible exhaust pipe (for photographs of these, see Fig. 6). In these measurements the machine had no cowl, but was fitted with the air-intake muffler.

A.	No muffler, no exhaust pipe	114 dBA
B.	Large car muffler (Dodge V-8)	91 dBA
C.	Continental muffler	98 dBA
D.	Small car muffler (Valiant, 6 cyl.)	91 dBA
E.	Stock muffler	93 dBA



A. Large Car Muffler
(Intended for Dodge V-8)

B. Continental Muffler



C. Small Car Muffler
(Intended for Valiant 6 cyl.)

D. Stock Muffler

Figure 6 Photographs showing the four mufflers used in the experiments and illustrating the manner in which they were installed at the end of the flexible exhaust pipe.

Curve A - A reference curve showing the noise spectrum of the machine without muffler or exhaust pipe.

Curve B - Photograph A: The large car muffler (Dodge V-8) provided the most exhaust muffling of the four units tested. Subjectively, it was clear that the main source of the remaining noise was the engine compartment. The characteristic 'whine' of the stock machine was substantially reduced and what was left was the clatter of machinery.

Curve C - Photograph B: At the other extreme one has the effect of using a muffler of the Continental or so-called 'Hollywood' type. This type of muffler is intended to impart "a rich, deep-throated" quality to the sound and, because there are no internal baffles, to provide a minimal obstruction to the exhaust flow. The shape of Curve C indicates a measure of success in achieving the advertised purpose of this muffler, in that the low frequencies have been affected very little and the higher frequencies have been considerably attenuated. The overall sound level was unnecessarily high (98 dBA) and the strongly impulsive character of the exhaust made it especially unpleasant.

Curve D - Photograph C: This car muffler (for a Valiant 6 cylinder) was chosen because of the potential of effective silencing in a smaller unit than that shown in Photograph A of Figure 5. The result, Curve D, was the same high frequency sound pressure levels as were measured with the larger car muffler (Curve B), but somewhat higher sound pressure levels at low frequencies. The latter would appear to be related to the smaller volume of the present muffler (400 cu. in. versus 600 cu. in.).

Curve E - Photograph D: Results with the stock muffler appear to be very similar to those obtained with the small car muffler (Curve D). The low frequency performances were virtually identical, but the high frequency levels were somewhat increased. Subjectively the sound was judged to have a 'tinny' character which was localized in the vicinity of the muffler can. It would seem that the shock waves in the exhaust gases were exciting mechanical resonances in the shell of the muffler and/or in some internal structures.

The result for the stock muffler attached to the flexible exhaust pipe (Curve E, Figure 5) prompted a comparison with that obtained using the same muffler installed in its original location (Curve B, Figure 3). These two curves are reproduced in Figure 7 as Curves I and II respectively. In the original location the exhaust is expelled under the machine at the front end of the long channel containing the track. In this way advantage is taken of any sound absorption provided by the snow under the machine and that which may be thrown into the track channel as the machine moves along. In practice, however, we find that the sound level is higher at middle and high frequencies when the muffler is in its original location. We feel this higher level is due to the fact that the muffler is bolted directly to the engine. This close mechanical coupling allows the shock of each explosion in the cylinder to excite the muffler shell into its metallic-sounding resonances, and thus contributes further to the engine compartment noise. The net effect was that the potential advantage of the snow absorption was not fully realized because of noise contributed through this and possibly other unresolved mechanisms.

Figure 7 also shows a sound spectrum for the machine with only the 30" long, 1½" diameter, flexible exhaust pipe (Curve III) and, for comparison, the spectrum of the machine with no muffler or exhaust pipe (Curve IV). The exhaust pipe does little to change the overall sound level. The dip in the spectrum in the 250 Hz band seems to be due to a pipe resonance which one may presume would be drastically reduced when a muffler is attached.

With reference to Figure 5 it is interesting to note that the sound spectra obtained with three of the mufflers (Curves B, D and E) are closely similar in the octave bands 500 Hz and above. It should not be inferred that these mufflers are all equal in performance at these frequencies, which is highly unlikely. It appears that the exhaust noise was reduced to such a degree that the predominant high frequency noise was coming from another source. Careful listening (and later results) indicated this source to be in the vicinity of the engine, rather than at the exhaust outlet.

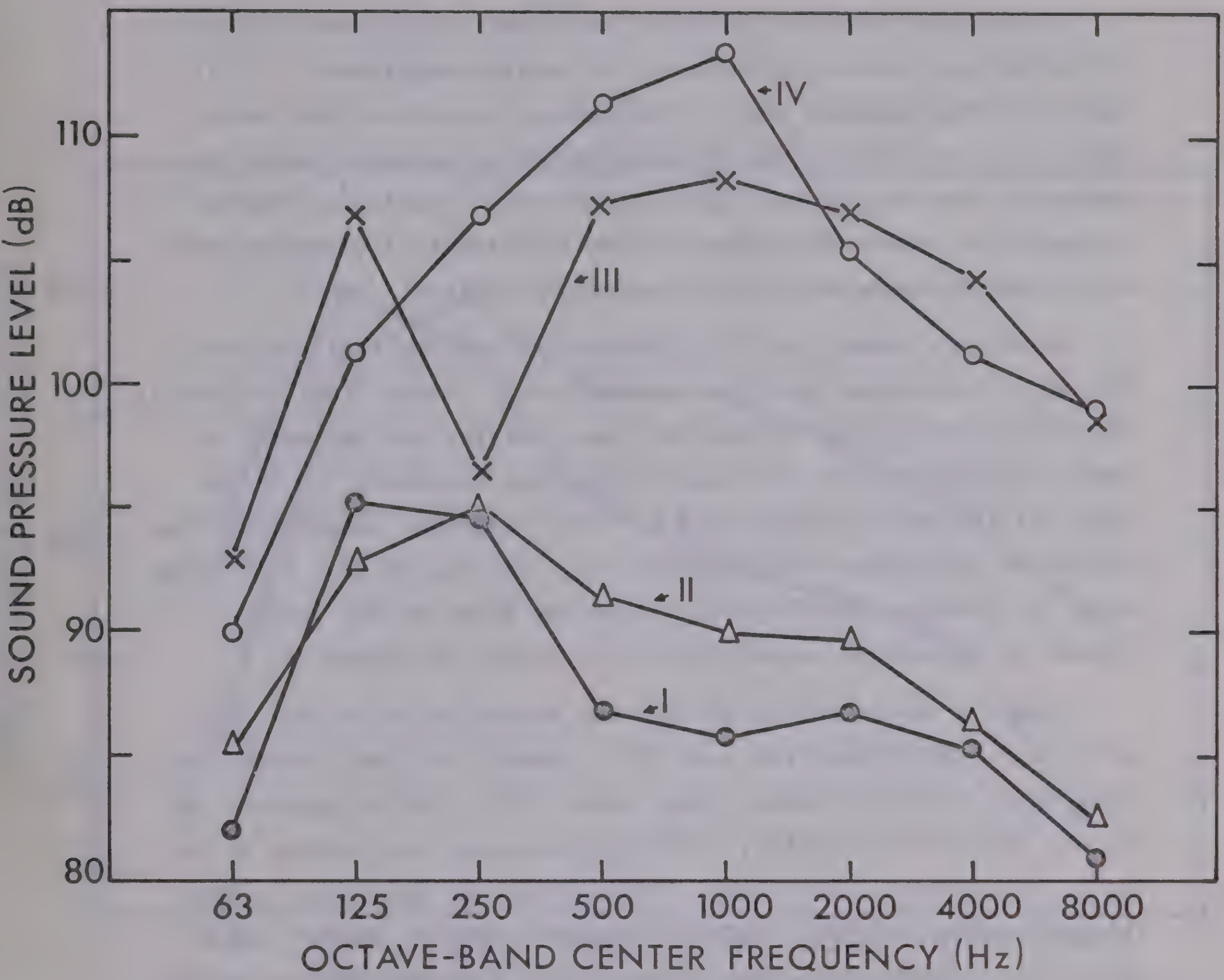


Figure 7 - Octave-band spectra for the test snowmobile in the experimental exhaust configurations described below. The machine had no cowl and was fitted with the intake muffler.

I	- Stock muffler at the end of 30" flexible exhaust pipe (see photograph, figure 6)	93 dBA
II	- Stock muffler in the original location (see photograph, figure 2)	96 dBA
III	- The 30" flexible exhaust pipe only. No muffler.	112 dBA
IV	- No muffler. No exhaust pipe	114 dBA

(ii) Noise from the Engine Compartment

Indications from the preceding experiments have been that much of the machine noise originates in the engine compartment. It is clear that the standard cowl is inadequate to contain this noise since it is not constructed of sound absorbing material and it is completely open on the end facing the driver. The latter feature is especially undesirable since it has the effect of directing much of the engine compartment noise towards the driver.

An obvious remedy for this problem was to completely enclose the engine compartment with an improved cowl. A cowl (not originally intended for this model of Ski-Doo) was modified and extended, by means of multiple layers of heavy corrugated cardboard, so as to block off the major openings and to cover (somewhat imperfectly) the portion of the engine facing the driver. See Figure 2D. A 1" thick layer of Fiberglas flexible duct-liner was glued to the inside surface of the entire assembly so as to absorb the sound.

Figure 8 shows the spectra for the machine with no cowl (A) and with the fully modified cowl (B). Clearly the cowl reduced the sound level in the frequency range above 500 Hz. which supports the notion, put forward earlier, that this noise was originating in the engine compartment. The overall sound level was reduced by 6 dBA. This reduction could be significantly improved with better cowl design and construction; there were serious imperfections in the ad hoc covering for the engine.

Air circulation for cooling the engine was not incorporated into the experimental cowl, but would obviously have to be provided in a practical installation.

In the snowmobile used for these tests the motor vibrations were isolated from the chassis by means of rubber mountings. We would judge from the low sound level (85 dBA) associated with the fully modified machine, that the component contributed by sound radiated from the chassis of the machine was at an acceptably low level. Evidently the standard motor mounts provide, at this level, sufficient mechanical isolation of the motor.

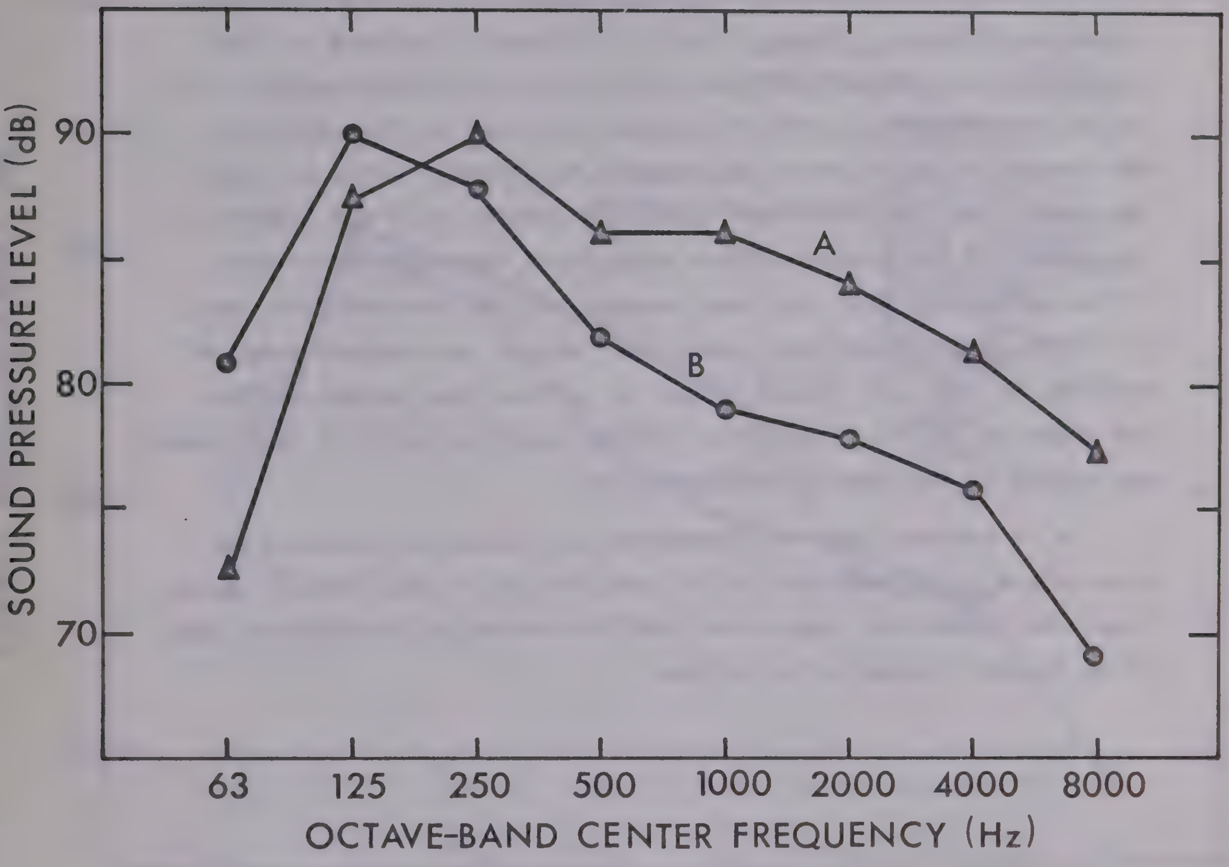


Figure 8 - A comparison of octave-band spectra for the test snowmobile to show the effect of the modified engine enclosure (cowl). In these tests the machine was fitted with the air intake muffler, the flexible exhaust pipe, large car muffler and tail pipe.

A.	- no cowl	91 dBA
B.	- with fully modified cowl	85 dBA

(iii) Noise from Carburetor Air Intake

In all measurements described in Parts (i) and (ii) of this Appendix the snowmobile was fitted with a simple muffler for the air intake. (See Part (i), the inset on Figure 9 and Figure 2C.)

To evaluate the acoustical performance of the intake muffler, it was now removed. Curves I and II of Figure 9 pertain to the fully modified machine with and without the air intake muffler. It can be seen that this muffler reduced the noise in the important mid-frequency octave bands and lowered the overall noise by 3 dBA. The sound level at the driver's ear was reduced by 5 dBA (Table I). The effect of the intake muffler might have been more noticeable if the carburetor duct had been brought outside the modified cowl; as it was, noise from this source was subject to a second stage of muffling by the cowl itself. Even so, without the intake muffler the sound of the air intake was clearly audible; with it this sound was buried in the general machine noise.

It is evident that the carburetor air intake is a source of noise which is significant in its contribution to the overall noise level and especially significant for the driver of the machine since it is located virtually in his lap.

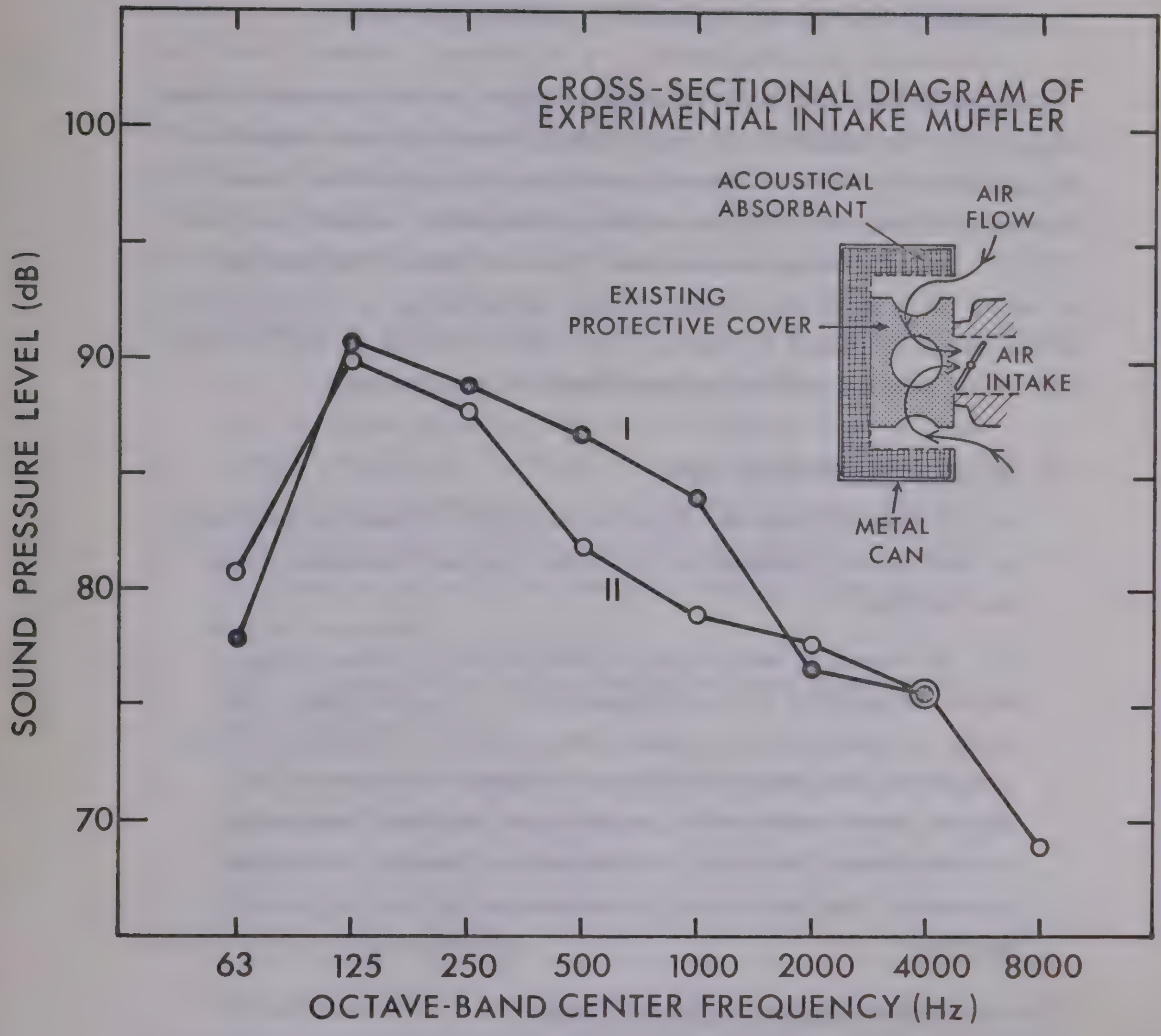


Figure 9 - A comparison of octave-band spectra showing the effect of the air-intake muffler. In these measurements the test snowmobile was fitted with the flexible exhaust pipe, large car muffler, tail pipe and fully modified cowl.

I - No air-intake muffler	88 dBA
II - With air-intake muffler	85 dBA

APPENDIX B

SUGGESTIONS FOR THE DESIGN OF A QUIETER SNOWMOBILE

In Appendix A the major sources of noise in the snowmobile were shown to be the exhaust, the engine compartment and the carburetor air intake. It has been demonstrated that the noise from these sources in a typical machine can be substantially reduced (Section 2.1(c)). The following suggestions, based on these findings, may be useful as a guide for a more serious undertaking to reduce snowmobile noise; it would be logical and most effective by far if this were to be done at the design and manufacturing stage.

(i) An Improved Exhaust System

(a) A flexible exhaust pipe (or one with a flexible portion) is desirable to mechanically isolate engine vibrations from the muffler.

(b) An improved muffler would substantially reduce exhaust noise, especially at low frequencies. It would appear that space is available (e.g. under the cowl) for a larger muffler. Certain of the acoustical design features of a normal car muffler could usefully be incorporated in a unit shaped to fit the chosen location. The interested reader is referred elsewhere[1] for authoritative information on the subject of mufflers.

(ii) An Improved Engine Enclosure (Cowl)

Several parts of the engine and drive train contribute to the noise originating in the engine compartment. The main source appears to be combustion noise radiated by the exterior of the engine. There are also audible contributions from the muffler (if it is rigidly attached) and some portions of the drive train. The latter could probably be alleviated by proper mechanical design and maintenance. The former, however, appears to be a characteristic feature of lightweight, air-cooled engines. With such an engine, significant noise reduction can only be achieved by efficient mechanical and acoustical isolation of the engine. The rubber engine mounts of the test snowmobile appeared to provide ample vibrational isolation. The standard cowl, however, left much to be desired.

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[1] "Fundamentals of Noise and Vibration Control", L. Beranek, ed. McGraw-Hill, In press.
Until this book becomes available, one may refer to the less comprehensive coverage of this subject to be found in: "Noise Reduction", L. Beranek, ed. McGraw-Hill, 1960. "Handbook of Noise Control", C. Harris, ed. McGraw-Hill, 1957.

An improved engine enclosure should have the following features:

(a) It should be as all-encompassing as is practical, with special attention being paid to the effectiveness of that portion immediately in front of the driver. Engine cooling could be accomplished with air conducted through ducts lined with sound absorbing material and opening either at the front or sides of the machine. Fan-assisted air flow may be required.

(b) The complete enclosure should be lined with sound absorbing material.

(c) The enclosure should have adequate mass and should be isolated from engine vibration. The design should avoid large flapping surfaces and rattles at joints and fixtures.

(iii) An Air-Intake Muffler

The muffling of the air intake could be made an integral part of the engine enclosure and ventilating system. The muffler itself could be similar in principle (not necessarily in design) to the one constructed for this machine and described in Appendix A. A simple can or duct could be acoustically lined and fitted with internal baffles which force the air flow (and the sound) to negotiate one or more 180° bends. The unit would have to be so constructed that the highly flammable fuel mixture, which may leak from the carburetor, cannot accumulate inside it (as it did in the experimental muffler).

APPENDIX C

SNOWMOBILE NOISE AS A HAZARD TO HEARING AND SAFETY

The snowmobile operator is immersed in steady noise of greater intensity than any he is likely to encounter in his other occupational and leisure pursuits. This is illustrated in Figure 10 which compares the noise spectrum of a typical snowmobile (Curve A) with that measured in a weaving mill (Curve B)[1]. The snowmobile may be used daily for many months of the year as a work vehicle, or less frequently for recreational purposes. In either case with such high noise levels, the hearing hazard should not be ignored.

(i) The CHABA Criteria

In 1965, the Committee on Hearing, Bioacoustics and Biomechanics (CHABA) of the U.S. National Academy of Science presented a report showing the maximum sound levels and daily durations of noise exposure believed to be tolerable. According to CHABA, a sound environment was "deemed acceptable if it produced, on the average, a permanent noise-induced hearing loss in people after 10 years or more of near-daily exposure of no more than 10 dB at 1000 Hz or below, no more than 15 dB at 2000 Hz and nor more than 20 dB at 3000 Hz or above"[2]. The limits of allowed exposure were defined so as to preserve the ability to understand speech for the majority of persons exposed near-daily for 10 years or longer. In 10% of the population - those highly susceptible to noise-induced hearing loss - much greater values of hearing loss were, however, predicted (30 dB at 1000 Hz, 45 dB at 2000 Hz and 60 dB at 3000 Hz). To identify such highly susceptible individuals before excessive damage had occurred, periodic audiometry was recommended for all individuals exposed to levels and durations of noise approaching the recommended limits.

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[1] Weavers exposed to mill noise are known to develop an appreciable hearing loss after 10 - 20 years of work. See "Noise and Man" by William Burns, p. 169, John Murray (London, 1968).

[2] "Hazardous Exposure to Intermittent and Steady-State Noise" by K.D. Kryter, W.D. Ward, J.D. Miller and D.H. Eldredge, Journal of the Acoustical Society of America 39, 451-464 (1966).

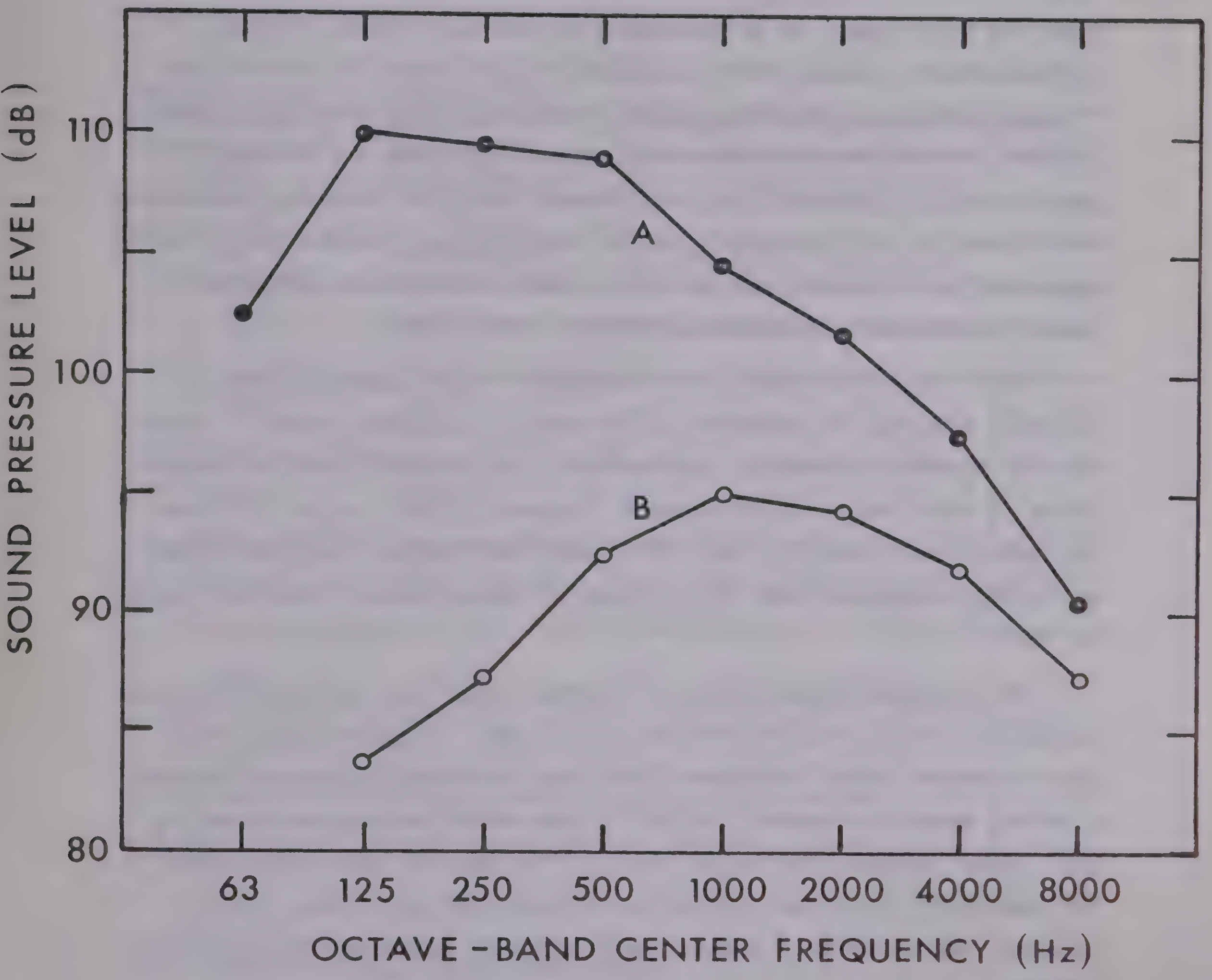

Figure 10 (A) Octave-band spectrum of the noise at the ear of a driver standing on the snowmobile. The one-cylinder stock machine was operated at full throttle.

(B) Spectrum of noise in a weaving mill (See Ref. 1.)

(ii) Snowmobile Noise and the CHABA Criteria

The CHABA criteria provide a direct means of determining acceptable exposure times for the person who uses his snowmobile daily, and can be extended to provide guidelines for all users. When the noise spectrum A of Figure 10 is evaluated according to these criteria it is found that a single daily exposure to such noise of no more than 9 minutes duration would be judged acceptable. Repeated noise bursts of more limited duration separated by quiet periods for recovery would also be allowable. In the present case, for example, the single daily exposure of 9 minutes could be replaced by 4-minute noise bursts separated by 10-minute rest periods. Such intermittent exposure could be continued throughout an 8-hour working day.

For a given dBA level, the acceptable daily exposure time is not much affected by moderate differences in spectrum shape[3]. Hence for the purpose of hearing conservation, the various spectrum shapes shown in this report (particularly, Figures 3C, 3D, 4A and 10A) can be treated as a single group. For these and similar spectrum shapes acceptable exposure times for a range of noise levels (dBA) are given in Table 2.

The measured noise levels at maximum power for the stock machines listed in Table 1 varied from 106 to 113 dBA. Similar values for other standard makes and models have been measured elsewhere, though a racing machine exceeded 120 dBA[4]. The modifications described in this report reduced the noise level of the one-cylinder machine at the operator's ear from 113 dBA to 103 dBA (Table 1) which would increase the acceptable single daily exposure duration from 6 to 25 minutes.

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[3] See "Simple Method for Identifying Acceptable Noise Exposures", J.H. Botsford, Journal of the Acoustical Society of America 42, 810-819 (1967).

[4] Private communication from P.H. Berry, Bureau of Air Quality Surveillance, Department of Health, State of New York, Albany, N.Y., U.S.A.

TABLE 2

Acceptable Daily Exposure Times for Various Levels of Snowmobile Noise Based on CHABA Criteria

Noise Level at Operator's Ear Position (dBA)	Maximum daily Duration of Single Continuous Exposure	Acceptable Intermittent Exposure Total time per day (on and Off) not to exceed 480 minutes
90	400 minutes	No practical restriction
95	120 "	50 minutes on, 4 minutes off, etc.
100	40 "	20 " " 7 " " "
* 105	18 "	10 " " 10 " " "
* 110	9 "	4 " " 10 " " "
* 115	5 "	2 " " 7 " " "
120	3 "	1 " " 4 " " "

* Typical Levels at the Operator's Ear with Several Existing Machines.

(iii) Recreational Use of Snowmobiles

Many people use their machines only one or two days per week for the winter months, or perhaps 25 days per year instead of the 250 working days in a normal industrial year. For such limited use it may be asked whether substantially greater exposure time than those given in Table 2 could be permitted without incurring excessive risk. There is no simple answer to this question, but it is known that a few prolonged exposure periods are much more damaging than many brief periods. For example, a 5-minute near-daily exposure at 115 dBA is considered acceptable throughout a period of 10 or more years, whereas a single continuous 24-hour exposure at the same level is known to cause irreversible damage to the inner ear[5].

The effect of increased durations of noise exposure depends greatly on the susceptibility of the individual person to noise-induced hearing loss (i.e. the 'tenderness' of his ears). For highly susceptible persons (perhaps 10% of a normal population) any increase in exposure times beyond those given would cause excessive temporary threshold shift with prolonged recovery which is probably associated with permanent damage. For the person of no more than average susceptibility, not engaged in any other noisy occupations or hobbies, exposure to snowmobile noise for a single 60-minute period per day 25 days per year might be acceptable. Since there is, at present, no practical means of identifying those individuals who have high susceptibility to noise-induced hearing loss, in advance of exposure, the use of proper hearing protectors (ear plugs or covers) is strongly recommended, especially when the exposure to snowmobile noise is likely to exceed the time limits shown in Table 2.

(iv) Precautionary Measures

The far-sighted person may ask whether the levels and exposure times shown in Table 2 are, in fact, 'safe'. In reply it must be emphasized that these exposures, if continued daily for ten or more years, are expected to produce, on the average, a small permanent hearing loss which has been deemed acceptable for the purpose of industrial noise control. For the highly susceptible individual a more serious loss is predicted. Furthermore, many snowbobile operators who use their machines for recreational purposes are also subjected to other environmental noise hazards such as industrial noise which must be included in a proper assessment of the hearing hazard.

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[5] Private Communication from J.D. Miller and D.H. Eldredge, Central Institute for the Deaf, St. Louis, Missouri, U.S.A.

Nevertheless, the prudent person can reduce the hazard by choosing one of the quieter machines and by operating his machine for brief periods interspersed with rest periods of adequate duration (Table 2). Virtually complete protection can be acheived by wearing hearing protectors which provide at least 20 dB of attenuation in the 500 - 4000 Hz band. Many ear plugs and sound-attenuating ear muffs meet this requirement but the typical crash helmet provides very little hearing protection.

(v) Safety - Ability to Hear Warning Signals

The typical snowmobile, when cruising, produces an overall level of approximately 108 dBA at the operator's ear, and a level of 105 dB in the 500 Hz octave band. A pure tone warning signal in this frequency band would be fully masked (i.e. inaudible) unless its sound pressure level exceeded 95 dB. This is the level of a typical automobile horn at 20 feet. (With the snowmobile idling the warning signal would still have to exceed 75 dB to be audible.) Hence the ability to hear warning signals is seriously impaired by the high level of machine noise.

It may be asked whether the use of ear plugs would further impair the ability of the operator to hear warning signals. This seems most unlikely. In fact, the ability to hear signals should be somewhat improved since, without hearing protection, the high level of noise overloads the hearing mechanism thus reducing intelligibility. Hence it is beneficial to reduce all sounds, wanted and unwanted, by 20 - 30 dB which can be accomplished with ear plugs.

Reduction of the machine noise to 90 dBA would not only make earplugs unnecessary but would greatly increase the distance at which other vehicles could be heard.

(vi) Recommendations for Hearing Conservation

1. The snowmobile manufacturer should reduce the noise level at the operator's ear to 90 dBA as soon as possible.

2. The operator should select the quietest machine available.
3. Unless an adequately quiet machine is used, the driver and passenger should protect their hearing by wearing ear plugs or covers.
4. When the use of earplugs or covers is not possible, the driver should restrict his operating times to the maximum values shown in Table 2. Brief operating periods interspersed with adequate recovery periods are preferred.

APPENDIX D

LEGISLATIVE CONTROL OF SNOWMOBILE NOISE

(i) Control by means of By-laws

In the report APS-467 it was suggested that the noise limit for snowmobiles should be 85 dBA at a distance of 15 feet. The level was chosen with two criteria in mind, viz., that it would not degrade the noise environment as determined at present by road vehicles and that, in view of the obvious popularity of snowmobiles, it should be feasible to meet this level. That the latter criterion is met is shown in this report. The former criterion might be considered to require the somewhat lower level of 83 dBA suggested for passenger cars. Since their number is considerably smaller than that of automobiles and the operating time is usually lower the higher limit of 85 dBA may be considered reasonable.

However since then there has been a tendency to restrict snowmobiles to large open areas such as parks. In such cases their annoyance to residential areas is decreased and consequently it is suggested that by-laws use a wording somewhat as follows.

> "No snowmobile or similar off-the-road vehicle shall be operated, or caused to be operated, whose noise level exceeds 85 dBA when measured at a distance of 15 feet or more except in specially designated open areas where this level shall be measured at a distance of 15 feet outside the boundary of the designated area."

(ii) Control at the Manufacturing Level

Local by-laws, in an attempt to control noise pollution and annoyance, consider the noise produced by the vehicle-driver combination. They do not consider explicitly the noise potential of the vehicle (the maximum noise that it can produce).

In the case of the snowmobile there is the further consideration of the risk to the driver and passenger of permanent hearing loss. (See Appendix C.) An effective way of minimizing this risk is to control the noise potential of the machine. This has the additional benefit of controlling also the pollution and annoyance. Alternatively the driver may wear ear protecting devices. Authorities must consider whether the responsibility for hearing conservation is to be left to the individual, to the manufacturer, or to government.

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